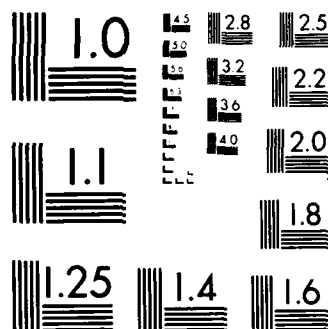


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THE EFFECT OF OCEAN FLUCTUATIONS ON SOUND TRANSMISSION IN THE OCEAN

FINAL TECHNICAL REPORT

October 1, 1977 to September 30, 1987

Contract No. N00014-77-C-0475

Principal Investigator: Stanley M. Flatté

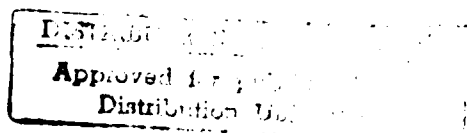
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SUMMARY

The objective of this work was to develop a general theoretical framework for calculating fluctuations of signals on waves propagated through random media (WPRM) and to apply this framework to sound through the ocean. Comparison with real data is an important aspect of the effort.

This report will consist of a summary (with list of references), followed by copies of the sixteen journal articles resulting from this contract that have been published, or have been accepted for publication. This contract helped to support the publication of a book¹ which is not available for forwarding, but it is available in libraries around the world.

The work has been carried out under the direction of Dr. Stanley Flatté, and involved effort by Dr. Flatté; post-doctoral researchers Drs. R. Leung, S. Reynolds, D. Creamer, and T. Duda; students D. Bernstein, R. Stoughton, and T. Moody; and a number of collaborators from other institutions.



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The path-integral method for treating wave propagation has been successfully used by the principal investigator for the analysis of many experiments in ocean acoustics. Much of this progress was recorded in the extensive book on ocean acoustic fluctuations which the Principal Investigator edited and coauthored.¹ An update of these results that summarized recent progress was contained in a review article published in the Proceedings of the IEEE in 1983.²

During the period of the contract, we have expended considerable effort in developing and exploiting means of calculating acoustic fluctuations that would be caused by internal waves in the ocean, where the internal waves are represented by a Garrett-Munk spectrum.³⁻⁶ We eventually chose to study the mutual coherence function (MCF) of the complex wave function of the wave field arriving at a receiver, and the behavior of certain aspects of the intensity distribution. We have developed quantitative treatments of these functions for waves in an anisotropic medium with curved deterministic rays,^{7,8} and have with good success applied these treatments to data from the AFAR 35-km, 5-kHz ocean-acoustic experiment,^{9,10} and other experiments.¹¹ The medium fluctuations in those experiments were measured by instruments that were independent of the acoustic information, so no free parameters were available to the theory.

In 1982, the Principal Investigator suggested the use of long-range acoustic propagation as a probe of the internal-wave spectrum.^{12,13}

Pulses sent through a fluctuating medium arrive earlier or later than they would in the absence of fluctuations, depending on the particular realization of the medium. The variance of arrival time can be calculated by straightforward methods in the geometrical optics limit. This variance is a direct probe of the internal-wave spectrum



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in the ocean. The feasibility of such a method was established in 1986 with the publication of the first measurement of the internal-wave spectrum using long-range low-frequency acoustic transmission.^{14,15}

Our progress in understanding the travel time of pulses in random media has resulted in a paper published in Physical Review Letters.¹⁶ Our dramatic new result is for the average arrival time, which we find biased away from the answer in the absence of small-scale fluctuations in weak random media. Heretofore, researchers were of the opinion that pulses were delayed on the average, while we find the possibility for either a delay or an advance. This effect is of little importance in communication applications where the average arrival time is usually less important than the variance. However, the effect can be important in probing a random medium for large-scale variations by their effect on average travel time. Our result implies a possible confusion between a changing turbulence level and a change in the average index of refraction on a large scale. For example, ocean acoustic tomography attempts to measure the warming of a 100-km-square area of the ocean by an expected change in travel time of about 20 ms. However we find a change in average travel time of about 10 ms, due to an internal-wavefield that has no average warming at all. We have recently studied the range dependence of this effect, and have found that it grows as the square of the range. This implies that experiments being planned in the 1000-4000 km region will have major difficulties sorting out the effects of internal waves from the effects of large-scale structure. Most importantly, the determinations of internal-wave effects will NOT be contaminated by the large-scale effects.¹⁷

In nearly all cases, in order to compare theory to experimental data in WPRM, we must use a model spectrum for the medium fluctuations. We are developing phenomenological spectra, as a function of wave vector, that allow for an anisotropic component added to a turbulent isotropic component.¹⁸ This model is meaningful both for the ocean, where the anisotropic component represents internal waves, and the ionosphere, where the anisotropy is due to electrons preferentially moving along magnetic field lines. We are in the process of calculating intensity spectra in the weak fluctuation region using these model spectra. We have data from an ocean-acoustic experiment that will be used for comparison purposes; the experiment utilized 10-70 kHz sound over several hundred meters under the Arctic ice. We should note that the weak-fluctuation regime is one in which the intensity series solution for the low-wave-number regime is the only relevant one.

In summary, we have made quantitative and reliable our ability to calculate the effects of internal waves on oceanic sound transmission, over a wide range of parameters. Ranges may vary from a few hundred meters to thousands of kilometers, while frequencies from 50 Hertz to 100 kHz can be treated. The future holds the prospect of exploiting this capability for vastly improved capability in probing ocean small-scale processes by the use of acoustics, as well as in the design of sonar systems.

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